

DEVELOPMENT COMPARISONS OF AL-SiC MMC USING STIR CASTING PROCESS AND POWDER METALLURGY PROCESS FOR AUTOMOTIVE INDUSTRIES

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ABSTRACT

Material selections for automotive industries are the very important role in the recent era. Presently used materials have some limitation like easily worn out, higher weight-to-strength ratio and life of components are shorter. To overcome this problem, we developed an Aluminium Silicon Carbide composite material which has a higher wear resistance, the higher strength-to-weight ratio that can be satisfied the requirement of automotive industries. First of all, we developed an Aluminium Silicon Carbide metal matrix composite using a stir casting process. Improving the mechanical properties of composite material, Silicon carbide is used as reinforcement in Aluminium matrix by varying the percentage of Silicon Carbide weight fraction (15, 20 and 30%). Secondly, development of Aluminium Silicon Carbide by powder metallurgy process with same Silicon Carbide percentage in Aluminium matrix. Developed Aluminium Silicon Carbide composite material properties have been checked by microstructure examination, strength and hardness and compared the developed Aluminium Silicon Carbide metal matrix composite materials properties by stir casting process and powder metallurgy process.

KEYWORDS: Al-SiC MMC with Weight Fraction of SiC, Stir Casting Process, Powder Metallurgy Process & Mechanical Properties

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1. INTRODUCTION

Composite materials play a crucial role in the field of engineering as well as in the aircrafts, aerospace, and automotive industries due to its unexampled demands, excellence mechanical properties, and advanced producing response. Composite materials are significantly superior in strength and modulus compared to several ancient engineering metals materials due to low density. Based on intensive studies of materials' nature and their structure-property relationship understanding, it might be possible to develop composite materials with better mechanical and physical properties, which include superior reinforced composite. That led to continuous improvement of composite materials used in the heterogeneous application. [1] Mostly Aluminium material is used in the aerospace and automotive industries due to lighter weight. But Aluminium has low strength and low melting point which always create a problem. To overcome this problem, SiC particles are added as reinforced elements in Aluminium, that replacing the use of super alloys in structural components applications.

Reinforcement particles are distributed into the molten metal matrix using mechanical stirring in stir-casting process. This process firstly introduced by S. Ray in 1968 for metal matrix composite preparation. They had used alumina particles into Aluminium alloys which contain ceramic powder using mechanical stirring process.

After that, the mixer of Aluminium and ceramic particles are used either for sand casting or die casting or permanent mold casting. This process is most suitable up to 30% volume fractions of reinforcement for composite manufacturing. [2]

Powder metallurgy has the advantage of producing net-shape parts to minimize the machining process that could be a downside in Al-SiC composite as the results of high tool wear, owing to the abrasiveness of the arduous SiC particles. Also, the machining process causes cracking of SiC particles and bondless matrix-reinforcement beneath the machined surface powder metallurgy (PM) methodology used to manufacture aluminium composite reinforcement with SiC particulates produce a regular distribution of reinforcement within the matrix.

2. LITERATURE REVIEW

Kratus Ranieri et al. [3] have suggested that for proper bonding between Alumina as a reinforcement particles and AA 356 alloys (Al-7Si-0.3Mg) as a matrix material in semi-solid state string process gave better result than fully liquid state string process. They also found that particle size and its initial fraction are most affecting factors and stir time is no matter for processing. Mg has been used for improving the wettability. Rajeshkumar et al. [4] presented an overall idea about stir casting process parameters and how to use aluminium as a matrix material and weight fraction variation of SiC, Al_2O_3 , and graphite as a reinforcement material for composite development. They have been observed that for uniform dispersion of particles blade angle kept as 45° or 60° with 4 numbers blade are required. Better wettability operating temperature need to keep at semi-solid stage of matrix material. To improve the mechanical properties and reducing porosity preheated mold are required. S. Amirkhanlou et al. [5] have made a composite of Al 356-5% SiCp (volume fraction) with 8 μm and 3 μm particles size of SiCp injected into fully liquid and semi-solid slurries of Al 356 alloy. They investigated the porosity, hardness and impact strength properties by injecting the different form of reinforcement particles in casting process. They found that the wettability has been improved between the molten metal matrix and reinforcement particles in semi-solid state casting process by decreases the SiCp particle size. J P Pathak et al. [7] performed experiment for the development of Al-Si-SiC composite using mechanical stirring speed 300 rpm with SiC powder (300 mesh) in semi-solid slurry of hypoeutectic, eutectic, hypereutectic compositions. Mixing time had taken as 3 to 4 minutes and system temperature dropped up to $15 \pm 5^\circ C$ from the liquidus temperature. Presence of SiC particles in composite material was analyzed by X-ray diffraction. They have been observed that strength, hardness and wear-resistance increased with SiC percentage increased in composite material. Purohit, [8] fabricate the Al-SiC Metal Matrix Composites with different Weighted percentage of SiC (5,10,15,20%) in Aluminium material using a horizontal ball milled have outer diameter 300mm, rotation speed 78rpm, Milling timing 12 hours and Sintering temperature $600^\circ C$ in Powder Metallurgy. They found that less bonding in green strength, high bonding after sintering. Porosity was increased with the percentage of SiC, more for green specimen than sintered specimens. Hardness and compressive strength was increased with the percentage of SiC increased. Tensile strength is increased upto 15% SiC after that very small increment in tensile strength. Chandra [9] developed Al-SiC, a functionally graded material composite with milling speed 150 rpm for 2 hour Compaction 370-400 KN for 5 min, sintering $600^\circ C$ for 3 hours in Powder Metallurgy Techniques. They used Mg as an additive material in Al-SiC composite material and found that the hardness and impact strength increased with the percentage of SiC, uniform distribution upto 10% SiC but above it give clustering effect, green density increased after the sintering, max hardness 44.8 (BHN) in 20% of SiC. Singh [10] prepared the Al-SiC composite with 6, 8 and 10% SiC. They used Hardness & wear testing under the 10, 20, 30, 40 and 50 N load of EN-32 steel ball with 1.6 m/s speed up to 30 min and they found that the wear and hardness property also increased with increasing the weight percentage of SiC. Rostamzadeh [11], a study of

microstructure on Al-5% SiC Nanocomposite powders using planetary ball mill with ball and powder ratio was 15:1, rotation speed 300rpm, size of steel balls had 12mm in argon gas atmosphere for 25 hours milling time. They found that the increased milling time work hardening, lattice strain increased, aluminium crystal size decreased, powder particles change from flaky to spherical. After 25 hours of milling time the average crystal size was 41nm and maximum lattice strain was 0.41%.

3. RAW MATERIAL SELECTION

It is necessary to select pure aluminium ingot, pure aluminium powder and SiC powder for specimens preparation. Aluminium ingot was obtained from local Ahmedabad market and did the spectro test for chemical composition as shown in table 1. Aluminium powder was got from Fine Chemical, Mumbai, India for powder metallurgy process and Silicon Carbide (SiC) powder having 320 mesh size was procured from local market of Ahmedabad, India. The fine powder was produced using 8 hours process time in ball milling. Figure 1 and figure 2 show the XRD analysis results of Al raw powders have 99% pure and SiC have 98% pure respectively.

Table 1: Aluminium Ingot Chemical Composition

AL	Fe	Cu	Mn	Si	Ti	Mesh Size
99 %	0.1 %	0.02 %	0.02%	0.1%	0.03%	120–20 μ m

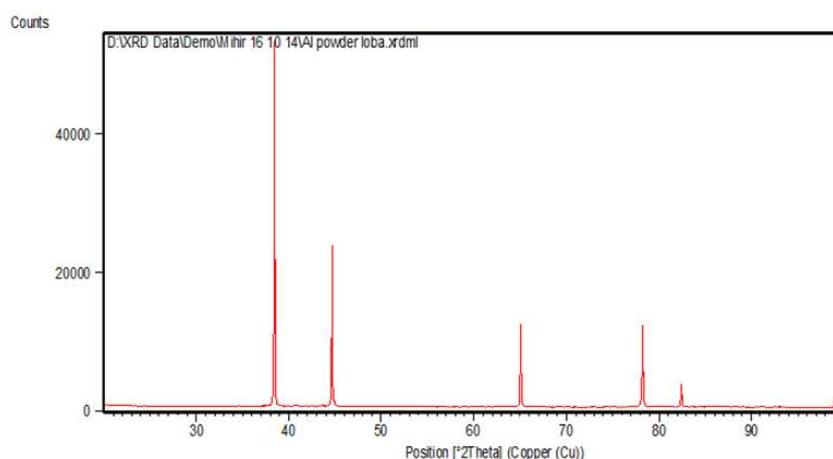


Figure 1: XRD of SiC Powder.

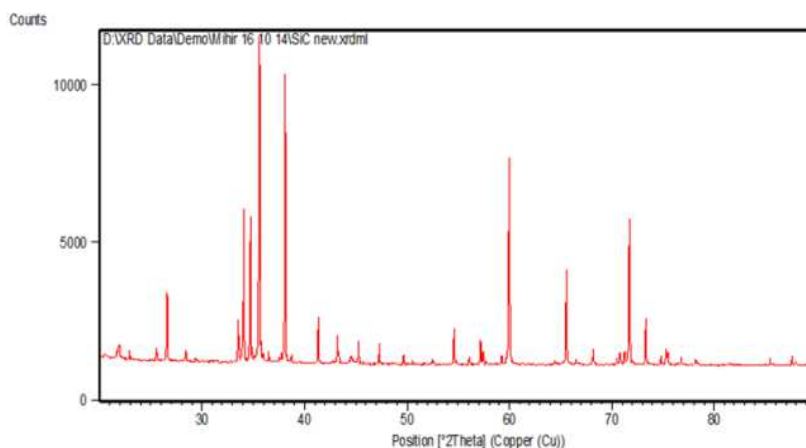


Figure 2: XRD of Aluminium Powder.

4. DEVELOPMENT - AL-SiC COMPOSITE MATERIAL BY STIR CASTING PROCESSES

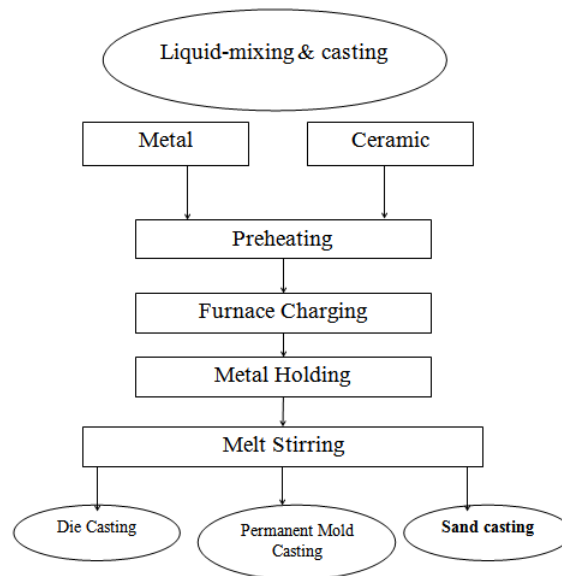


Figure 3: Process Flow of Stir Casting Process.

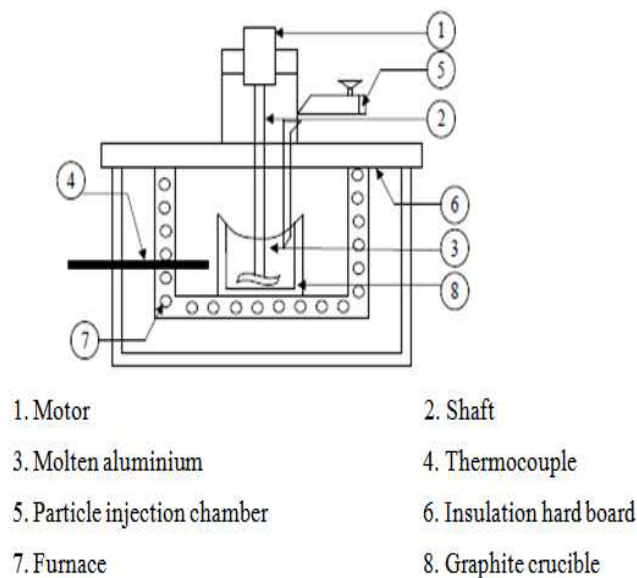


Figure 4: Schematic Diagram of Stir Casting Processes Set-up [11].

Stir casting has been carried out using graphite stirrer, which is held by the hand drill. Aluminium ingot is melted at 660°C in graphite crucible of coal-fired furnace than after cooled down up to semi-solid condition and Degasser tablet 109 is added during melting of Aluminium to remove the impurities from Aluminium ingot. SiC powders are preheated at 1000°C for 2 hours in the separate electrical furnace to remove the moisture from SiC powder. After preheated SiC powder (15%, 20%, and 30%) are manually added in Aluminium slurry because the automatic mechanism is quite difficult to mix the alloys in semi-solid state condition. To improve the wettability between Al and SiC particles 1% magnesium is added in a mixer slurry. After sufficient manual mixing, the whole composite slurry is again reheated up to fully liquid state, than automatic mixing has been carried out using hand drill held by graphite stirrer for 5 minutes with 600 rpm stirring speed in controlled furnace temperature at $760 \pm 100^\circ\text{C}$. Pour the composite slurry in sand mold as shown in below figure 5.

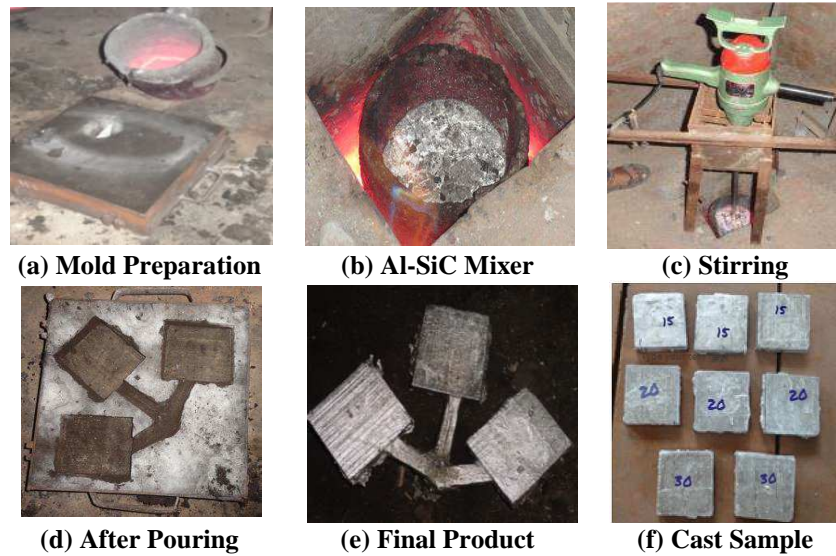


Figure 5: Stir Casting Process Steps.

4. 1. Sem Micrographs of Stir Casting Process

The optical microscope is used to examine the microstructure of samples shows in figure 6. Microstructure shows that the SiC particles are trapped between primary α Al dendrites. Uniform distribution of SiC particles are shown in the microstructure of 15% SiC sample. However, some SiC particles were not bonded during solidification because of particles pushing effect and agglomeration of particles.

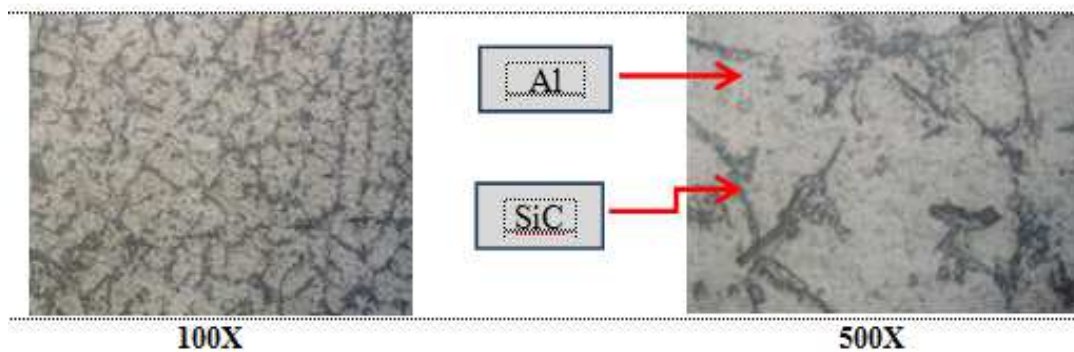


Figure 6: SEM Micrographs of Cast Sample (Al-15% SiC).

5. DEVELOPMENTS AL-SiC COMPOSITE MATERIAL BY POWDER METALLURGY

Composition ratio is depended on the requirement of the property of the parts. The ratio of SiC % varied in the terms of 15%, 20%, and 30%. Balled-mixing, according to the weight percentage of the composite, powders are to be weighted on the digital weight machine. That weighted powder has to be mixed by using small beaker. Initially, manual mixing has been carried out for one hour. High energy ball milling process involved preheating, fracturing and welding of powder particles to produce solid-state mechanical alloy in Powder metallurgy. Ball milling process has been carried out in a vacuum to prevent oxidation. Compaction, the mixer of powder is put under the mechanical or hydraulic operated press to impact the pressure on the component. Sintering, heat the sample for sufficient time at an elevated temperature in controllable condition and maintain the temperature below the melting point of Aluminium. [13]

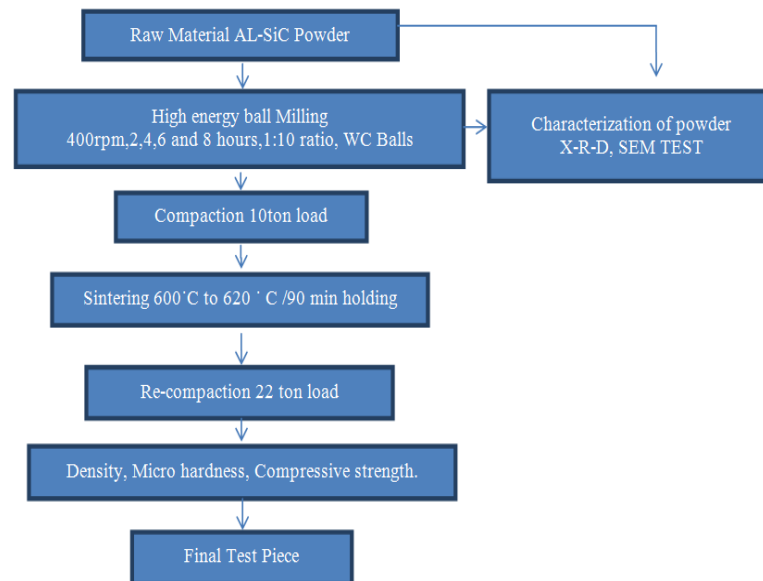


Figure 7: Process Flow Diagram of Powder Metallurgy Process.

X-ray diffraction (XRD) confirms the present of SiC particles in the blended powder specimen. Eight hours time is required to reduce the grain size up to 34 nm of SiC particles in ball milling process.

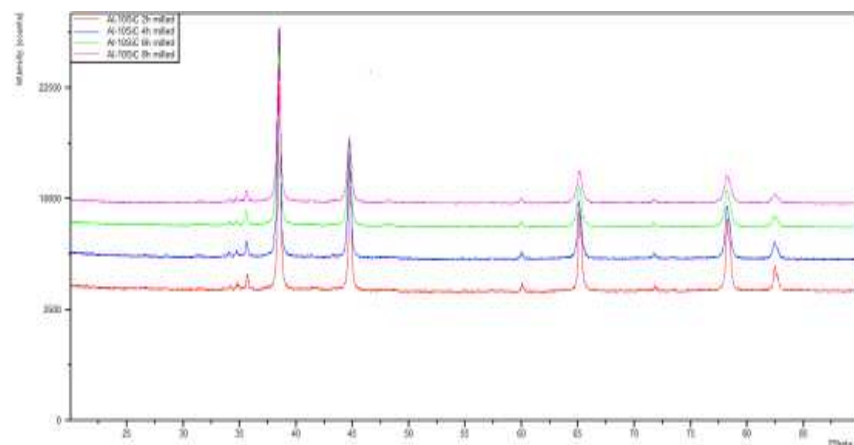


Figure 8: XRD of Al-SiC Blended Powder Specimen.

5. 1. Ball Milling Time and Particle Size

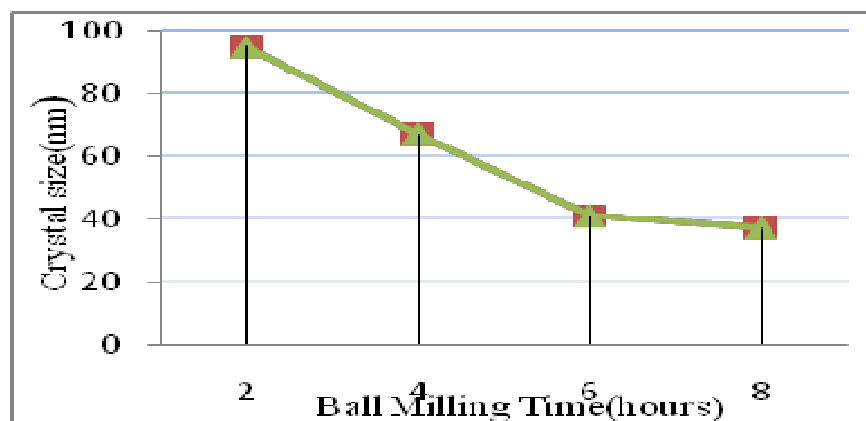


Figure 9: Relation of Ball Milling Time and Particle Size.

Finding the size of the particles is based on equation $L = K\lambda / B \cos\theta$, Where, L =Particle size, K =shape factor-1, λ = wave length 1.54060 \AA , B =Corrected FWHM (Radians), $\theta=1/2 2\theta$ (peak position).

5. 2. Scanning Electron Microscopy Examination

The shape of the Aluminum powder is in the round & tiny shape while SiC is sharp and thin. After the 4 hours of Ball milling process, welding has been taking place between the particles. After the 8 hours of milling, fracturing takes place and particle size reduced. As shown in below figure 10.

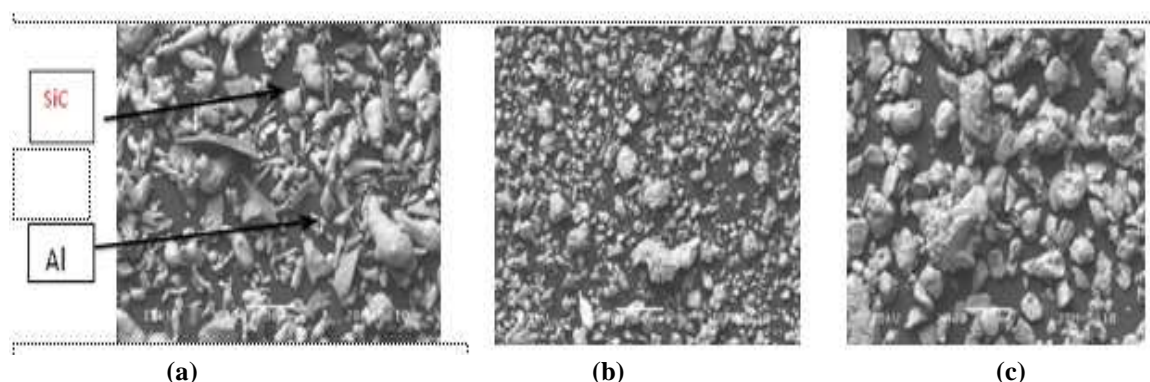


Figure 10: SEM Micrographs for Al-SiC Ball Mill Composite Powder (a) 2 hr. Mill, (b) 4 hr. Mill, (c) 8hr. Mill.

Due to the sintering process, the porosity in specimen is removed and that increase the strength of the components. The densities of prepared specimens are given below table 2.

Table 2: Density Calculation of Al-SiC Composite Material with Different % of SiC in Al

Al-SiC Composite Material	Theoretical Density (g/cm ³)	Green Density in (g/cm ³)	Sintering Density in (g/cm ³)	Re-compaction Density in (g/cm ³)
Al-15% SiC	2.76	2.08	2.03	2.26
Al-20% SiC	2.79	2.11	2.07	2.29
Al-30% SiC	2.84	2.19	2.10	2.33

5. 3. Density

Theoretical density of powder mixtures signify the maximum material density acquired in the last phase, where zero porosity is considered ideal and is calculated by using below relationship:

$$\rho_{\text{mixture}} = \frac{100}{\sum x_i / \rho_i} \quad (1)$$

Where x_i is the fraction component i in mixture (i being Al and SiC) ρ_i is the component density (g/cm³).

6. RESULTS AND DISCUSSIONS

Sample specimens of Al-SiC were developed by varying percentage fraction of SiC (15%, 20%, and 30% respectively) in Aluminium matrix using the stir casting and powder metallurgy process. SiC particles reinforced in Aluminum matrix were not present in Al-SiC(20%) and Al- SiC(30%) sample of stir-casting process. But, in Al-SiC(15%) sample SiC was reinforced in Aluminum matrix material and observed. In case of powder metallurgy process, it obtained the proper bonding between Al and SiC particles. Microstructure analysis, Micro-hardness test and Compressive strength have been carried on cast composite as well as powder metallurgy composite samples.

6.1. Macrostructure Analysis

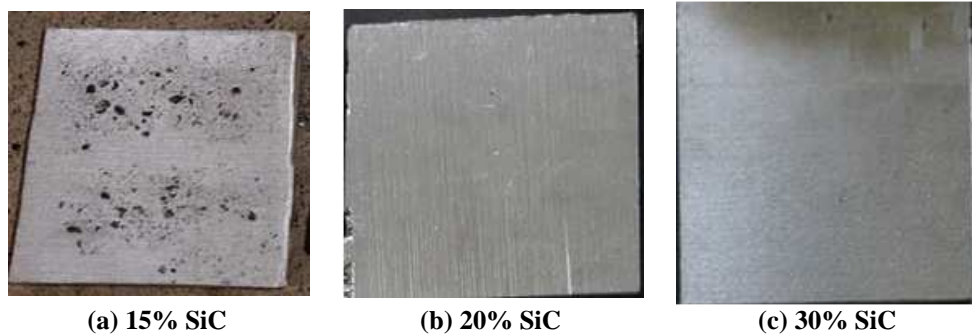


Figure 11: Al-SiC Stir Casting Component.

The microstructure of stir-casting process samples of 15%, 20% and 30% SiC in Aluminium matrix were shown in figure 11 a, 11 b and 11 c. In 15% SiC sample porosity were formed in metal matrix composite of stir casting sample, due to the air bubbles presents in the mixer, gas entrapment in casting and shrinkage during solidification. Even SiC particles were not uniformly distributed or not settle down properly and particles were clusters in the sample as shown in figure 6.

The microstructure analysis has been carried out using an electron probe analyzer of pressed and sintered materials. That confirmed the SiC (15, 20 and 30%) were present in the powder metallurgy process as shown in figure 10. It was also observed that the appearances of SiC particles were in round shape with proportional quantity in Aluminium matrix. Al phase and SiC were present, which confirmed that both the material completely dissolved into each other in composite material which is shown in figure 12.

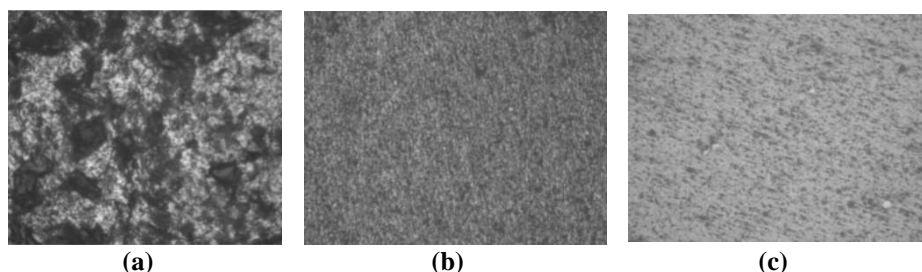


Figure 12: Microstructure of Al-SiC Polished Pellet : (a) 15% Ball-Mixed SiC, (b) 20% Ball Mixed SiC, (c) 30% Ball Mixed SiC

6.2. Hardness Test

The experimental data are shown in table 3. Hardness indentation of 0.1 HV at the top surface of the cast plate for both processes with 100gf load and dwell time 30 second.

Table 3: Micro-Hardness Comparison of Al-SiC Composite

Sr. No.	Al-SiC composite	Stir Casting Process Samples	Powder Metallurgy Process Samples
1	Aluminium -15% SiC (320 mesh $\approx 45\mu\text{m}$)	76 HV	110 HV
2	Aluminium -20% SiC	71 HV	135 HV
3	Aaluminium-30% SiC	72 HV	140 HV

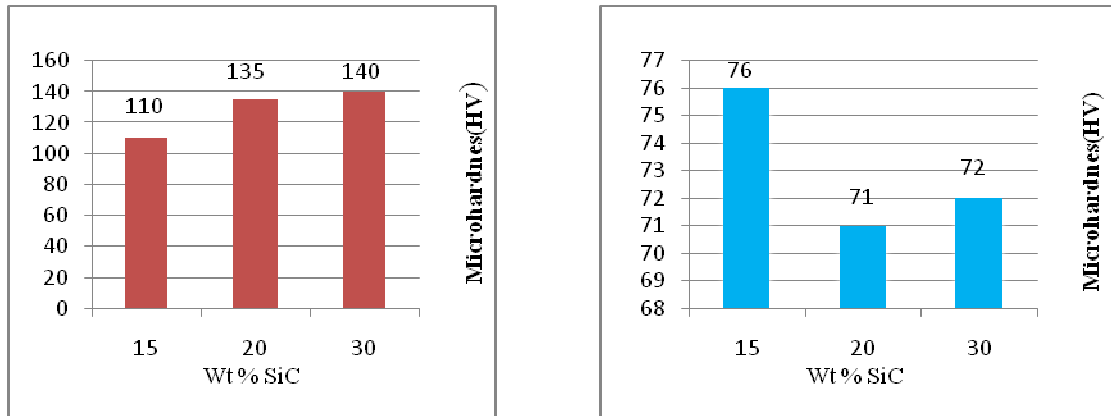


Figure 13: Micro-Hardness Comparison Between Stir Casting and Powder Metallurgy Process.

Micro-hardness of stir casting processed samples have been found 76 HV in 15% SiC due to porosity formed during the development of the Al-SiC composite material. Micro-hardness is affected due to poor bonding between Al and SiC particles. It was also found that 20% and 30% of SiC samples hardness were not improved because of the poor wettability between particles.

Micro-hardness of Al-SiC composite material was increased with increasing the weight percentage of SiC in Powder metallurgy process because of proper bonding obtained between Al and SiC particles at 8hour milling time.

6.3. Compressive Strength Test

Performed the compressive strength test has been carried out on the universal testing machine with max loading capacity 400KN and the speed of compression was 2 mm/s on the both processed sample.

Table 4: Compressive Strength Comparison of Al-SiC Composite.

Sr. No.	Al-SiC composite	Stir Casting Process Samples	Powder Metallurgy Process Samples
1	Aluminium -15% SiC (320 mesh $\approx 45\mu\text{m}$)	98 N/mm ²	198 N/mm ²
2	Aluminium -20% SiC	102 N/mm ²	230 N/mm ²
3	Aaluminium-30% SiC	108 N/mm ²	250 N/mm ²

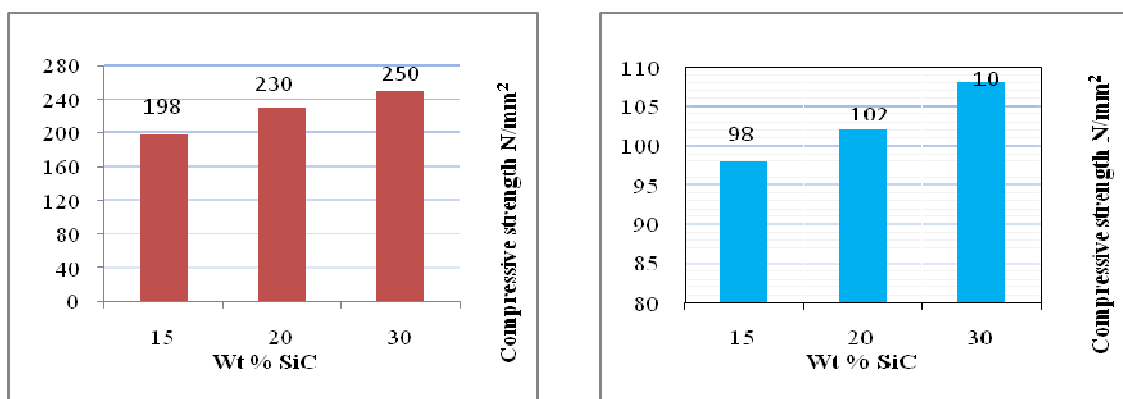


Figure 14: Compressive Strength Comparisons between Stir Casting and Powder Metallurgy Process.

Compressive strength has been increased with increasing the percentage of SiC in powder metallurgy process because of proper bonding between Al and SiC particles. But in stir casting process have not improvement in compressive strength due to porosity formed in components.

7. CONCLUSIONS

- Al-SiC composite material by varying weighted fraction of 20% and 30% SiC could not developed successfully because of gas layers present in molten metal in stir casting process. Hence, it get poor wettability between reinforced SiC particles and Aluminium matrix particles.
- During experimental study in stir casting process, it is observed that the micro-hardness is increased from 70 HV to 76HV and compressive strength is increased from 85 N/mm² to 98 N/mm² of Al-SiC composite having a 15% SiC in Aluminium matrix material compared to without adding any reinforcing material.
- Micro-structural of Al-SiC composite material having a 15% SiC investigations discovered that the larger sizes (more than 40µm) of reinforced SiC particles are not uniformly distributed in Aluminium matrix material in stir casting process.
- Porosity formation is found in 15% SiC sample of metal matrix composite in stir casting product, due to the air bubbles presents in the mixer, gas entrapment in casting and shrinkage during solidification.
- In ball milling process, Al and SiC particles are fractured and bonded due to centrifugal and impact forces applied by different size of Tungsten Carbide (WC) balls. Figure 8 shows the maximum reduction of grain size of Al-SiC composite powder has been found at 8 hours ball mill time with 400 rpm milling speed.
- Density of Al-SiC composite material have been improved from 2.10 g/cm³ to 2.33 g/cm³ in 30% SiC balled mill sample due to 22 T re-pressing load.
- It has been found that as the percentage of SiC (20% to 30%) increased in Al matrix, the micro-hardness is increased from 71 HV to 72 HV and compressive strength is also increased from 98 N/mm² to 108 N/mm² in stir-casting process. Same as in balled mill powder micro-hardness is increased from 135 HV to 140 HV and compressive strength is increased from 230 N/mm² to 250 N/mm². So, high-energy balled milling process appeared to be more suitable for the production of composite material.

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